U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-258 829-T

Vehicle-Generated Pollutant Diffusion Module in Open-Air Conditions (Samplings Along a One-Way Highway)

Environmental Protection Agency, Research Triangle Park, N C

1971

300010

PB 258 829-T

APTIC 43638

EPA-IR 433-74

VEHICLE-GENERATED POLLUTANT DIFFUSION MODULE IN OPEN-AIR CONDITIONS

(Samplings Along a One-Way Highway)

[Modulo di diffusione di inquinanti veicolari in ambiente aperto

(Sperimentazion lungo una via di grande traffico a senso unico)]

Geofisica e. Meteorologia, Vol. 20
March-August 1971, pp. 106-114.

Translated for the
ENVIRONMENTAL PROTECTION AGENCY
by
Translation Consultants, Ltd., Arlington, Virginia

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

(26)

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA TR74-433	2.	3. Recipient's Accession No.
4. Title and Subtitle: Vehicle generated pollutant diffusion module in open air conditions			5. Report Date: March-August 1971 6.
7. Author(s): L. Mammarella and A.L. Santi			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: TRANSLATED FROM ITALIAN BY EPA			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address: Translation Service, Office of Administration - Library, Research Triangle Park, NC 27711			13. Type of Report & Period Covered 14.

15. Supplementary Notes: GEOFISICA e. METEOROLOGIA, VOL. 20, March-August 1971, pp.106-114

16. Abstracts

17. Key Words and Document Analysis. 17a. Descriptors: EPAISD

17b. Identifiers/Open-Ended Terms: AIR POLLUTION - SOURCES

17c. COSATI Field/Group 13B 68A

PRICES SUBJECT TO CHANGE

18. Availability Statement: NTIS HAS BEEN GRANTED PERMISSION TO STORE AND DISTRIBUTE COPIES OF THIS TEXT i.	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 26
	20. Security Class (This Page) UNCLASSIFIED	22. Price 4.00-3.00

FORM NTIS-35 (10-70)

USCOMM-DC 40329-P71

L. Mammarella*, A.L. Santi**

VEHICLE-GENERATED POLLUTANT DIFFUSION MODULE IN OPEN-AIR CONDITIONS

(Samplings Along a One-Way Highway)

I. Foreword.

Of the three types of atmospheric pollution (thermal, vehicular, industrial), the first two are those largely responsible for the change that takes place in the composition of the low-lying urban air strata.

Vehicular traffic, while in a different category than the heating processes, must be considered of great importance, and, from the point of view of interest in its effects (especially on health) must be regarded with great suspicion. This statement is based on three considerations:

(1) vehicular traffic, as distinguished from home heating, casts a pall over cities the year round, thus forming a sort of permanent substratum which emits a high level of pollutants, qualitatively as well as quantitatively;

(2) whereas the products emitted by the heating process, and combustion in general, are qualitatively less diversified and subject to certain cutting and controlling procedures, control of vehicular emissions must be considered absolutely unsatisfactory;

(3) the increase in the number of vehicles in cities is continuous;

---

* Institute of Atmospheric Physics of the C.N.R. 31 Piazzale Luigi sturso, 00144 Roma-EUR.

** Institute of Hygiene - University of Rome.

and so too is the consumption of automotive fuel. These two factors result in a continuous increase in emissions.

Moreover, the pollutants emitted by the combustion of automotive fuel are highly diversified. These emissions, from the point of view of possible damage to human health and to the economy, can be added to those of other combustible products and thus greatly expand overlapping spheres.

Many characterization studies have emphasized the urban atmospheric pollution aspect in Italy [1-10]. There is, in addition, a series of experimental studies [11, 12, 13] reported by one of the authors of this paper. This series studied the same urban center (Rome) used to collect the data for this paper.

Before describing the tests, we believe it will be of interest to set down the complex of automotive emissions as they apply to the urban area studied.

II. Vehicle-generated pollutants.

Vehicular emissions play a big role in low altitude urban pollution. In fact, as opposed to emissions from heating sources, which can be considered as lying between 30 to 60 meters from the ground, those from vehicular sources are practically at ground level. This factor, together with very dense traffic patterns tends to restrict overlapping spheres of vehicular emissions on the streets or on highways. A phenomenon of this type, particularly when the town topography is considered to be of the "closed" type, tends to concentrate vehicular emissions for a long time. It is clear that in these cases even the large masses of people who move

about or stop in urban centers become interested parties. It is also clear that there is a high probability of damage to structures or materials along the routes followed by major traffic flows, or in the immediate vicinity of such flows.

Specific vehicle-generated pollutants are considerably diversified, qualitatively and quantitatively.

The principal representatives of pollutants are listed in Table 1, but we deem it useful to describe, if briefly, those terms.

Aerosols.

From a quantitative point of view, the presence of these pollutants is small (200-300 grams per average daily consumption by 1000 vehicles), but they tend to be so small in size (5 micron and smaller) and the composition of the particles is such that this component is extremely important.

In fact, this material is essentially organic in nature, and is more or less carbonized. Other different substances are absorbed in this solid and semisolid phase, making a nucleus which rarely is inert more active and reactive.

A constituent certainly not secondary in importance among the automotive aerosols is formed by the lead derived from the addition of tetraethyl, or tetramethyl lead, to gasoline.

Table I: Mean daily emissions of principal pollutants per 1000 vehicles moving in one day in the U.S. (Chambers).

Pollutants	kg
Aerosols	0.3
Aldehydes	16-18
Organic acids	2
Ammonia	2
Sulfur dioxide	14-16
Hydrocarbons	200-400
Oxides of nitrogen	50-150
Carbon monoxide	3,200

A broad study of atmospheric pollution in Italy [15], calculated the annual emissions in our country (in 1967) at 10,000 tons. It is clear that the major aliquots, and the more dangerous, were found in urban areas with heavy vehicular traffic.

Materials in the gaseous or vapor phases.

Virtually all other vehicular pollutants fall into this category. They range from large representative values (carbon monoxide, the mean for which is slightly less than 50% of a given weight of gasoline burned) to values, which, while smaller, always are important (unburned or partially burned hydrocarbons, various organic bases, oxides of nitrogen, etc.).

The awareness of the evaluation of these aspects is broad and well documented.

The characterizations of certain of these constituents are particularly important. Among the Italian studies (foreign literature on the subject too is very heavy), mention should be made of the studies by the Rome Sanitary School on characterizations of carbon monoxide and of polycyclic

aromatic hydrocarbons [16-20]. Another class of pollutants, oxides of nitrogen, has been the subject of numerous studies. On this score, it is useful to mention a recent study made of the interference of these substances with urban visibility [21].

Of the classes of the above-mentioned pollutants (aerosols and gases or vapors), it is always easier to characterize the first. In fact, gas or vapor sampling either is very simple (and the characterization consequently is uncertain and in any case spotty), or quite complex. In the latter case, the availability of more than one sample is not always possible.

The techniques of dynamic aerosol sampling are much more certain; so in this study we used this second type of confirmation, as will be explained in what follows.

III. The present vehicular traffic situation.

This subject deals in particular with the city of Rome. Pollution of the areas sampled occurred immediately afterward.

The study of the characterization of atmospheric pollution in Italy [15], hypothicated a total emission of over 11 million tons in 1967. Of this quantity, at least 3,500,000 tons of pollutants were attributed to vehicular traffic.

A great deal of partial data were derived from the study. In particular, vehicular emissions in the city of Rome in 1967, were quantified at at least 370,000 tons. Table 2 lists total urban emissions.

Table II. Estimate of actual immissions of non-industrial pollutants in Rome, 1967, in tons. (from Mammarella).

	Annual consumption of energy sources	Aerosols	SO_2	NO_2	Various pollutants (H_2S, CO, aldehydes, etc.)
coal	100,000	10,000	3,000	500	18,000
fuel oils	700,000	280	42,000	4,900	21,000
motor fuels	650,000	30	325	3,900	295,000
		10,310	45,325	9,300	334,000
		Estimated emissions			398,935
		Actual Immissions (40%)			160,000

The vehicular evolution since 1967, has increased in Rome, as in any other Italian city. The number of vehicles in use in Rome in 1967, was approximately 650,000. This figure increased to 765,000 [22] in 1968, reached 900,000 in 1970, and approached 1 million in 1971 (estimated data).

Motor fuel consumption increased from 650,000 tons in 1967, to 740,000 in 1968, 800,000 in 1969, and, according to estimates, 900,000 in 1970.

Given this state of affairs, a continuous increase on emissions is a foregone conclusion.

IV. Purpose of this study.

In the light of what has been said, it appeared to be of great practical importance to undertake a statistically valid investigation of vehicular contamination of some part of the city of Rome characterized by heavy traffic, but variable during daily rush hours.

This sort of check has been made many times in the past, as the Italian bibliography (chosen from a great many references) shows.

But when looked at critically, none of the results obtained to date are definitive. The reason, in our view, can be found in the procedures used and, in many cases, in the equipment used.

While it is true that carbon monoxide is the heaviest vehicular pollutant exhausted, it also is true that because of the high coefficient of diffusibility of this gas, data must be very numerous before they can assume a statistically acceptable value. Moreover, as is all too often the case when collecting such data, instantaneous samplers are used. These samplers, while capable of gathering a great deal of data in unit time, tend to provide point pollution data such that the data cannot be expanded, however short the projected radius from the point.

We decided to use the vehicular aerosol component as the pollution reference in order to eliminate, to the maximum extent possible, these uncertainties, and because this component is the least of the pollutants exhausted by traffic, percentagewise, as we have shown in Table I. Moreover, its scope, the much simpler sampling methods, that can be used, and the possibility of differential "screening" of the morphology of the trapped aerosold, all encouraged us to take this approach.

The area we chose to examine was a section of street in the historical center of Rome (Via Capo le Case), a downhill, one-way street (from the higher to the lower level). The samplers were set up on the right side of the street, along which the traffic density was greatest, at a distance of about 20 meters from a traffic light. This made it possible to monitor the

traffic aerosol level, while at the same time taking into account fluctuations in levels because of traffic having to wait for a green light.

Three modified Whirimpactors [23] were used simultaneously. The equipment is described below.

The samplers were installed along the right wall of the street, at heights of 50 cm, 3 m, and 6 m above street level so as to amply and completely monitor vehicular pollution, and the behavior of this pollution at different heights.

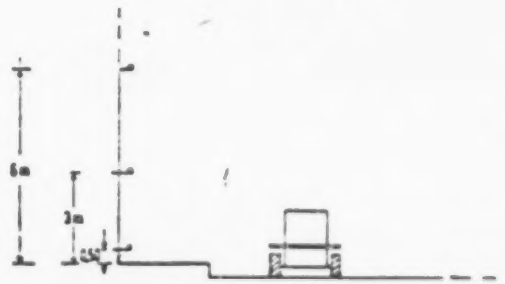

Figure 1. Schematic diagram of the installation of aerosol samplers in street section and building vertical.

The installation of the samplers as described seemed a logical one because of the discharge and dilution capacities of aerosols of different particle sizes and is in accordance with the experimental results obtained by various authors, and by one of us in particular [24], in characterizing the fine dust component at the various heights in a confined area.

V. Materials and methods.

Relative humidity, temperature, mean frequency of traffic, and wind were monitored. The equipment used was an Assmann hygrometer, and a Salmoiraghi anemometer.

The aerosol sampling apparatus was the "Whirimpactor", which one of us modified.

The sampler (fig. 2) consists of a base containing two supply batteries, on which is mounted a motor rotating at 1000 rpm.

Mounted on the motor shaft is a plastic circular support with a circular crown of material that can pick up aerosols in its vicinity.

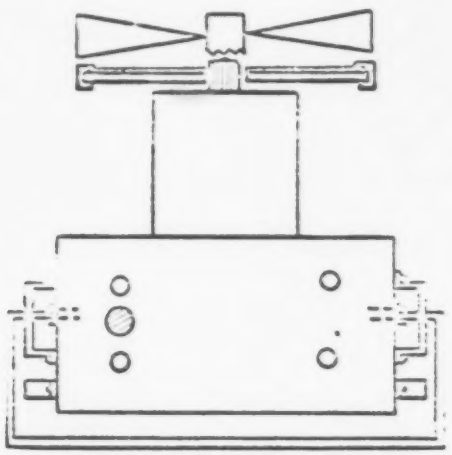

Figure 2. Directed impaction sampler (modified Whirimpactor).

The aerosols are converged by rotation of a six-bladed propeller keyed to the motor shaft.

The apparatus has a standard performance rating of about 1 liter of air per minute.

The difference in angular speeds of the propeller at different radii from the center causes quantities of aerosols to be deposited on the sampler according to particle size in descending order from the center to the periphery.

Reference [25] contains a more detailed description of the equipment.

The samplers described were used in this study over three hour periods. The collection surface was changed at the end of each three hour period, placed in a suitable numbered container, and sent to the laboratory for evaluation.

The collection surfaces (Millipore AA 0037 filters - porosity 0.8 micron) were coated with a thin film of silicone grease to increase collection capability.

Equipment used:

1 Salmoiraghi anemometer,

1 Assmann hygrometer,

3 Mammarella collision conveyor samplers.

Methodology

Wind conditions (speed and direction) were recorded every three hours.

Temperature and humidity too were recorded every three hours.

The samplers were run continuously from 1100 to 2000 hours, changing the collectors every three hours, according to the following schedule. There were, therefore, three series of collections each sampling day, one series for each sampler, as follows:

1st series: 1100 to 1300 hours

2nd " 1500 to 1700 hours

3rd " 1800 to 2000 hours

This schedule was adopted to test the average movement of local vehicular pollution most representative of vehicular traffic (very high in late morning, high in the afternoon, average in the evening). These periods were chosen after a preliminary examination of circulation in the area under study.

In addition, because the experimental study was made during a period of home heating, the sampling hours, as listed above, resulted in less influence being exerted by combustion pollution, at least for the Rome area, as can be seen from the data on the matter previously ascertained over a long period of monitoring [11-13].

Period and duration of sampling.

Sampling took place between 11 and 13 March, 1971. The three days analyzed were chosen because of light cloud cover and average temperature and humidity conditions.

The total was 27 samplings (9 per day, 3 per sampler per day).

VI. Results.

The results are given separately for meteorological and pollution data. These data will serve as the basis for the interpretation of the data as a whole in the conclusions.

(A) Meteorological and climatic conditions.

These conditions were, on the whole, very similar. The sky was clear for almost the entire experimental period.

Temperatures were rather high (between 14° and 17° C) in clear sun during daylight hours. The relative humidity was within rather narrow limits (45% to 55%).

The wind was very calm, with no significant readings until the second day of the tests, when there was a slight ascending wind (from the lower to the higher part of the street), with a speed of between 2 and 3 m/s.

Table 3 lists synthesis of the meteorological data.

Given the similarity of the meteorological data recorded, the three day period of sampling is quite significant.

(B) Directed impaction sampling.

Before considering the results obtained, we think it is useful to mention, if only briefly, the findings relative to the mechanics of the deposition of aerosols on the circular collecting crown, and to refer to technical publication [25] for a better idea of the phenomenon.

Microscopic examination of a representative series of samples made it possible to ascertain that the distribution of particles was practically uniform from a numerical point of view along the diametrical directrix of the aerosol collection surface. The particle size analysis, on the other hand, showed variations in a discrete range according to distance from the center of the circular collecting surface.

Table 4 lists a representative sampling of the numerical distribution at various distances. The data on aerosol samples are listed for 4 diametrical directions, perpendicular to each other.

Table III. Meteorological and climatic conditions on Via Capo le Case during the period 11 - 13 March 1971, during the hours of direct impaction sampling.

Date and time	Visibility and insolation	Temperture (°C)	Relative Humidity	Wind (m/s)
11 March '71				
hours 11-13	clear	14°	48%	none
hours 15-17	coveres 2/8	16°	45%	none
hours 18-20	coveres 2/8	15°	47%	none
12 March '71				
hours 11-13	clear	15°	52%	1 m/s
hours 15-17	clear	16°	55%	2 m/s
hours 18-20	clear	15°	57%	3 m/s
13 March '71				
hours 11-13	clear	14°	51%	none
hours 15-17	clear	15°	53%	none
hours 18-20	clear	14°	58%	none

The collecting surface is a circular crown with a development of about 10 cm^2, and the surface has 10 microscopic fields in the radial direction of about 12.2 mm^2 (magnification x 100), so the correlation factor is about 80.

Table IV. Behavior of the numerical distribution of particles counted in 4 perpendicular directions on a surface for collection by directed impaction.

Microscopic field values (from periphery to center) 100 x	1st direction	2nd direction	3rd direction	4th direction
1	60	54	56	45
2	39	48	50	50
3	44	44	63	47
4	60	62	66	55
5	47	45	42	51
6	41	48	54	50
7	62	76	57	50

Microscopic field values (from periphery to center) 100 x	1st direction	2nd direction	3rd direction	4th direction
8	60	100	76	40
9	64	100	90	50
10	50	80	120	80
Total	525	654	674	528

Average of 4 radial readings: $\frac{525 + 654 + 674 + 528}{4} = 596$

Therefore the numerical interpretation of the collecting listed in Table 4 (corresponding to collection C_9 of 13 March 1971, is:

$$586 \cdot 80 = 48{,}000.$$

So far as the diametrical distribution along the successive concentric circular crowns on the filter surface is concerned, three orders of diameters were taken into consideration:

above 15 microns

between 15 and 5 microns

below 5 microns.

After a long series of readings, it was noted that the particle sizes between 5 and 15 microns were represented along nearly all the radii of the collector, with a slight increase in the percentage on the central circular crown.

The larger particles (above 15 microns) were found toward the outside with their number diminishing regularly toward the center.

The smaller particles (under 5 microns), on the other hand, are more numerous toward the center of the disc, and decrease gradually with increase in the radius.

While we have referred to [25] for the evaluation methodology, here we think it is important to mention that it is useful to divide the deposit on the sampler into three size percentages (according to the diameter values shown).

To complete the example as listed in Table 4, and analysed as explained, of the 48,000 particles counted on the sampler, 20% are aerosols with a diameter of $\geq$ 15 microns, 30% are average aerosols, and 60% are $\leq$ 5 micron aerosols.

(C) Examination of impactors used in the experiment.

Having given a brief outline on the method used, let us now describe the results obtained, as shown by analysis of 27 impactors used in the experiments.

For purposes of clarity, we have given the impactors mounted on the samplers 50 cm off the ground the letter A, followed by a progressive number for the sample (from 1 to 9). The impactors mounted on the sampler 3 meters off the ground were assigned the letter B (1 to 9), and those mounted on the samplers 6 meters off the ground, the letter C (1 to 9).

Table 5 lists the results.

Table V. Summary of the number of particles found on the 27 impactors used in the experiments.

day and position	No. of particles found		
	hour 1-13	hour 15-17	hour 18-20
11 March 71			
A (cm 50)	A1) 58.000	A2) 124.000	A3) 93.000
B (m 3)	B1) 48.000	B2) 78.000	B3) 54.000
C (m 6)	C1) 51.000	C2) 54.000	C3) 43.000
12 March 71			
A (cm 50)	A4) 104.000	A5) 184.000	A6) 53.000
B (m 3)	B4) 128.000	B5) 141.000	B6) 64.000
C (m 6)	C4) 52.000	C5) 37.000	C6) 49.000
13 March 71			
A (cm 50)	A7) 57.000	A8) 68.000	A9) 57.000
B (m 3)	B7) 45.000	B8) 55.000	B9) 42.000
C (m 6)	C7) 41.000	C8) 34.000	C9) 48.000

Normally, the largest number of particles was found at the lowest level (A samplers) in each series. The decrease in particles, and the increase in the number collected (series B and C) was almost constant. A larger number of particles were found at higher levels (especially at 3 meters, series B, with respect to the 50 cm one), on 12 March, when air movements of average value took place from the low to the high part of the street (remember that Capo le Case is a hill).

A better characterization of the phenomenon may be seen in Figure 3.

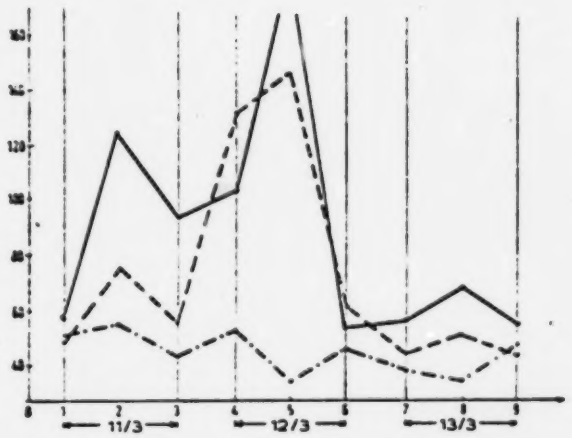

Figure 3. Plots of concentrations of particles sampled during the three days of experimentation.

In so far as the particle sizes prevailing at the various levels, and at the various times of collection are concerned, there is a clear movement of diameter values toward small sizes (under 5 microns) as the number of samples increases. In fact, the A (50 cm) collections show a mean percentage of large aerosols of 25% (with points up to 35%), as compared to an average for small aerosols of around 40%.

The B collections (3 meters off the ground) showed a mean pollution of 15% (large aerosols) and 47-48% (small aerosols).

The C collections (6 meters off street level) showed heavy pollution of the order of 12%, and mean fine pollution of 55% (with two points at 60% on six collections).

Pollution by aerosols from 5 to 15 microns is almost constant at all levels (mean 40%).

The pattern for 12 March sampling was not linear because of the light, steady breeze. The wind made the collections irregular, though medium and

small aerosols show the same type of diffusion as on the other two days of sampling.

The results are listed in Table 6, and Figure 4 shows the same results plotted on Cartesian axes.

The presentation of the results can be considered complete by observing the iconographs in Figure 5, which show the dimensions and shape of the aerosols trapped on the various circular crowns of the directional impactors.

All the evidence, particularly Figure 4 clearly shows an increase in small aerosols with increase in relative height of the sampler. At the same time, the decrease in the larger aerosols for the same conditions, is obvious.

The uniformity of the distribution of medium sized aerosols seems clear. The only anomaly in behavior is found here in the A 5 collection (with wind).

VII. Conclusions.

The tests would appear to have great practical importance. In fact, an investigation of the type described above can be made by using a setup that would include even more equipment because the cost of the sampler is low, and the sampler is very easy to operate. The long life of the batteries, and, most important, complete independence from a centralized power source, permit sampling to be done in any environment.

As opposed to many other systems in use to study polluting gases, the one described in this study, can be programmed for periods of 1, 2, and more hours, according to the needs of the investigation.

When we want to sample gases, or vapors, the choice is generally limited to equipment with absorbing cells (immediate collection, and statistically not very valid) or to more complex means, (scrubbers, or reaction cells, or some other method), the operating time of which must be rather long if the results are to have practical significance.

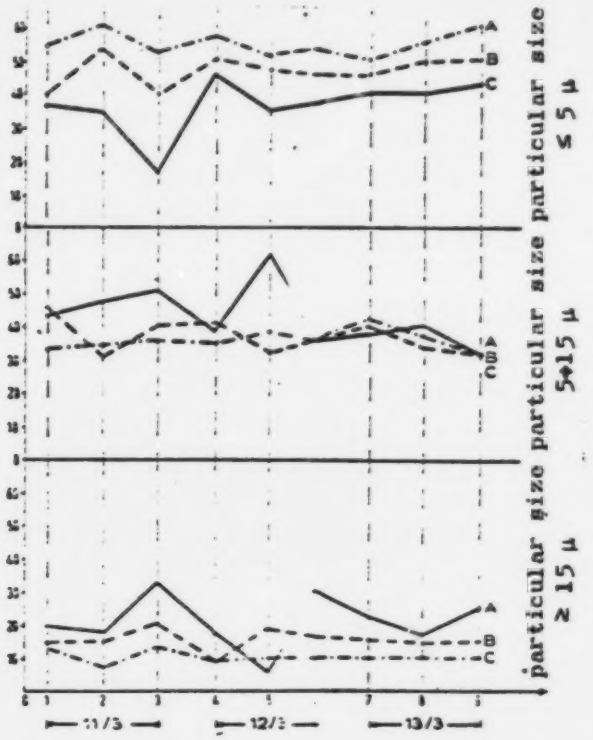

Figure 4. Cartesian representation of the distribution of aerosols tested by particle size as a function of the test level.

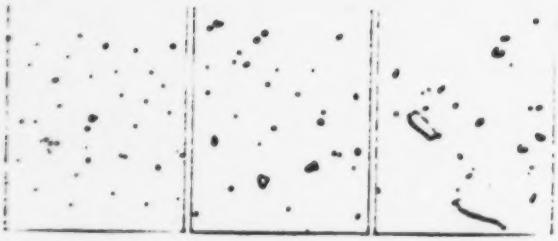

Figure 5. Iconographs of three microscopic fields, from left to right, of the inside, middle, and outside of the circular crown (magnification about 300x).

Table VI. Distribution of aerosols trapped during the tests by particle size (percentage).

day and position	Particular size analysis (% by size)								
	hour 11-13			hour 15-17			hour 18-20		
	≥ 15 μ	15-5 μ	≤ 5 μ	≥ 15 μ	15-5 μ	≤ 5 μ	≥ 15 μ	15-5 μ	≤ 5 μ
11.3.71									
A (50 cm)	20	42	38	18	16	36	35	50	15
B (3 m)	15	45	40	15	30	55	20	40	50
C (6 m)	13	32	55	7	33	60	12	35	53
12.3.71									
A (50 cm)	16	36	47	6	34	60	30	35	35
B (3 m)	9	39	51	20	32	48	18	36	46
C (6 m)	9	34	57	10	38	52	10	35	55
13.3.71									
A (50 ...)	22	38	40	15	40	45	25	32	43
B (3 m)	15	40	45	15	35	50	15	34	50
C (6 m)	10	40	50	10	35	55	10	30	60

In the latter case, however, what is obtained is the mean of the partial values for the whole of the test period. Finally, the difficulty in having more than one piece of equipment to study diffusion at different levels is obvious, and this does not take into account the need for specialized personnel.

But going back to more direct concern for the experiments involved in this study, we chose a sampling period of three hours for each series of collections because we assumed this period of time would be long enough to obtain an answer that would meet the test of statistical acceptability without becoming involved with mean values that would have been difficult to interperet.

The daytime sampling period seemed quite satisfactory to characterize traffic pollution conditions.

Interpretation of the data leads to the conclusion that pollution is heaviest at the low levels (to about 3 meters) during rush hours. At slightly higher levels (6 meters for the case in point), the mean pollution level tends to decrease, though remaining constant (see Table 5 and Figure 3).

The rapid and constant increase in minute aerosols with increase in level about the street is a clear index of the diffusion of gases and vapors as well, and of which minute aerosols follow the diffusion model [26-28]. From this point of view, it is our opinion that certain intermediate solutions should be proposed before we can achieve efficient control of vehicle pollution by resorting to means to reduce exhaust pollution, or motor fumes in general. These include:

(1) channel the traffic along one-way streets, whenever possible;

(2) change the arrangement of exhaust pipes, particularly those of heavy vehicles from the horizontal to the vertical.

The first proposal will provide for better diffusion and therefore for the better dilution of pollutants. Pollutants will tend to assume an ascensional dynamism caused by a series of swirls originated by unidirectional

air movements around the vehicles, as well as by normal mechanical diffusion.

The adoption of vertical exhaust pipes tends to move the exhaust gases upward, thereby facilitating dilution.

The Rome Municipality is moving in both of these directions. The second solution has, at least in part, been adopted for public transportation equipment.

Nevertheless, more emphasis must be placed on both proposals.

By doing so, we should be able to take a step forward in reducing the vehicular contamination phenomenon, which, in some areas of many urban centers, is massive.

BIBLIOGRAPHY

1. Dardanoni, L., Gullotti, A., Spanò, R., Zaffiro, P., "Present situation and future view of atmospheric pollution in the city of Palermo," Rivista Italiana d'Igiene, Vol. 22, 1962, pp. 412-436.

2. Del Vecchio, V., K'Arca, S.U., Talenti, M., "Carbon monoxidism and carbon monoxide in the atmosphere in the city of Rome," Nuovi Annali d'Igiene e Microbologia, Vol. 7, 1956, pp. 81-106.

3. Fabio, U., Olivo, R., Vivoli, G., "Observation and survey of atmospheric pollution in the city of Modena," Igiene Moderna, Vol. 56, 1963, pp. 314-341.

4. Giovanardi, A., Salvaggio, L., "Atmospheric pollution with particular regard to basic pollution as problem of public health," Study Convention on the Juridical and Hygienic Aspects of Atmospheric Pollution, Venezia, November 1965, pp. 5-7.

5. Giubilec, M., "Study of the pollution produced by motor vehicle exhaust pipes in the city of Milan," Medicina del Lavoro (Occupational Medicine), Vol. 48, 1957, pp. 165-186.

6. Liberti,A., Cantuti, V., "Determination of aromatic polycyclic hydrocarbons in urban dust," Nuovi Annali di Igiene e Microbiologia, Vol. XV, 1964, pp. 502-510.

7. Kanitz, S., "Present aspects of atmospheric pollution because of vehicle traffic," First National Social Medicine, (1965, mentioned in [4]).

8. Signorini, L., Guerra, M., Boccadoro, F., "On the problem of atmospheric pollution in Florence because of motor vehicle traffic," Modern Hygiene, Vol. 55, 1963, pp. 503-534.

9. Valori, P., Melchiorri, C., Vescia, N., "Research and determination of aromatic polycyclic hydrocarbons in atmospheric dust in the city of Rome," Nuovi Annali di Igiene e Microbiologia, Vol. 14, 1963, pp. 434-446.

10. Zurlo, N., Griffini, A.M., "Dust concentration in the Milan atmosphere," Provincial Study Center on Atmospheric Pollution, Milan, Vol. 2, 1958, pp. 56-60, Vol. 3, 1959, pp. 256-262.

11. Mammarella, L., Biondi, A., "Atmospheric pollution in the city of Rome," Nuovi Annali di Igiene e di Microbiologia, Vol. XX, 1969, pp. 208-237.

12. Mammarella, L., "The quarterly survey of atmospheric pollution in the city of Rome," New Annals of Hygiene and Microbiology, Vol. XX, 1969, pp. 524-555.

13. Mammerella, L., Cerquiglini-Monteriolo, S., "Behavior of atmospheric pollution during the winter in a Roman urban area," New Annals of Hygiene and Microbiology, Vol. XXI, 1970, pp. 275-289.

14. Chambers, L.A., "Where does air pollution come from?," Proc. Nat. Conference on Air Pollution, U.S. Dept. of Health, Ed. and Welfare, Washington, November 1958, pp. 34-38.

15. Mammarella, L., "Atmospheric pollution in Italy; principal,technical, scientific, and economic aspects," Documents I.S.V.E.T., Rome, 1970, p. 145.

16. D'Arca, S., Gualdi, G., Arcieri, G., "Investigations and considerations on the existance of carbon monoxide in some highway tunnels in the city of Rome," New Annals of Hygiene and Microb., Vol. XXV, 1964, pp. 200-220.

17. Del Vecchio, V., "Urban atmospheric pollution," Roport of the convention on atmospheric pollution, Problems of Public Health, Rome Campidoglio, April 1966, pp. 13-14.

18. Del Vecchio, V., Valori, P., et al., "Aromatic polycyclic hydrocarbons in escape gases of gasoline and liquid gas driven motor vehicles," New Annals of Hygiene and Microb., Vol. XX, 1969, pp. 193-207.

19. Valori, P., "Urban atmospheric pollution and its hygienic and medical aspects," Report of the Convention on Air and Water Pollution, Roma, 27 May 1968.

20. Del Vecchio, V., Valori, P., Grella, A., Melchiorri, C., "Atmospheric pollution from motor vehicles and problems related to its control," Il Pensiero Scientifico Editore, Roma, 1970.

21. Mammarella, L., "Effects on visibility," in Air pollution, edited by F. Siniscalco and G. Elias, PEG Editrice, Milan, 1970, pp. 152-168.

22. Ministero Industria e Commercio: "Oil industry in Italy, 1968."

23. Mammarella, L., "Sampling of aerosols by a mobile rotating collector system," In print, in New Annals of Hygiene and Microbiology.

24. Mammarella, L., Melino, C., "Aerosol pollution in confined spaces, etc.," Human Work, Vol. XXII, No. 2, 1970, pp. 3-20.

25. Mammarella, L., "Sampling aerosols by a directed impaction system," In print, in New Annals of Hygiene and Microbiology.

26. Stern, A.C., Air Pollution, II Edition, Academic Press, New York, 1968.

27. Magill, P.L., Holden, F., Ackley, C., Air Pollution Handbook, McGraw Hill, New York, 1956.

28. Mammarella, L., "Air pollution, diffusion, and monitoring," Il Pensiero Scientifico Editore, Roma, 1968.